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Art. V.—*The Igneous Rocks of North-Eastern Benambra.*

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Contents.

Introduction

The igneous rocks described in this paper outcrop in the north-eastern portion of the County of Benambra, where it is enclosed by the great right-angle bend of the Murray River. The area comprises the parishes of Adjie, Berringama*, Burrowye*, Canabore*, Colac Colac, Cudgewa, Jemba, Jinjellic, Kancobin*, Koetong*, Thowgla, Tintaldra, Towong, Wabba, Walwa, and Welumba* (part only of those marked with an asterisk), and is about 36 miles long by 30 miles broad. It has been geologically surveyed by Mr. J. Easton, of the Geological Survey of Victoria, and his contoured geological maps of the several parishes were published in 1920, on a scale of 2 inches to the mile.

Acknowledgments.

Mr. Easton has contributed the field work and general geology, on which the paper is based. Dr. Edwards is responsible for the petrological and theoretical sections, and for the form of the paper.

Our thanks are due to Mr. W. Baragwanath, Director of the Geological Survey of Victoria, for permission to use specimens and thin sections in the collections of the Geological Survey, and a set of seven unpublished rock analyses, made in the Survey Laboratories by Mr. F. F. Field; and to Professor Skeats, for laboratory facilities and the use of specimens and thin sections in the collections of the University of Melbourne.

Topography

As will be clear from the contours of the geological map (Fig. 1), the north-eastern portion of the County of Benambra is a deeply dissected tract of mountainous country, sloping, as a whole, towards the north.

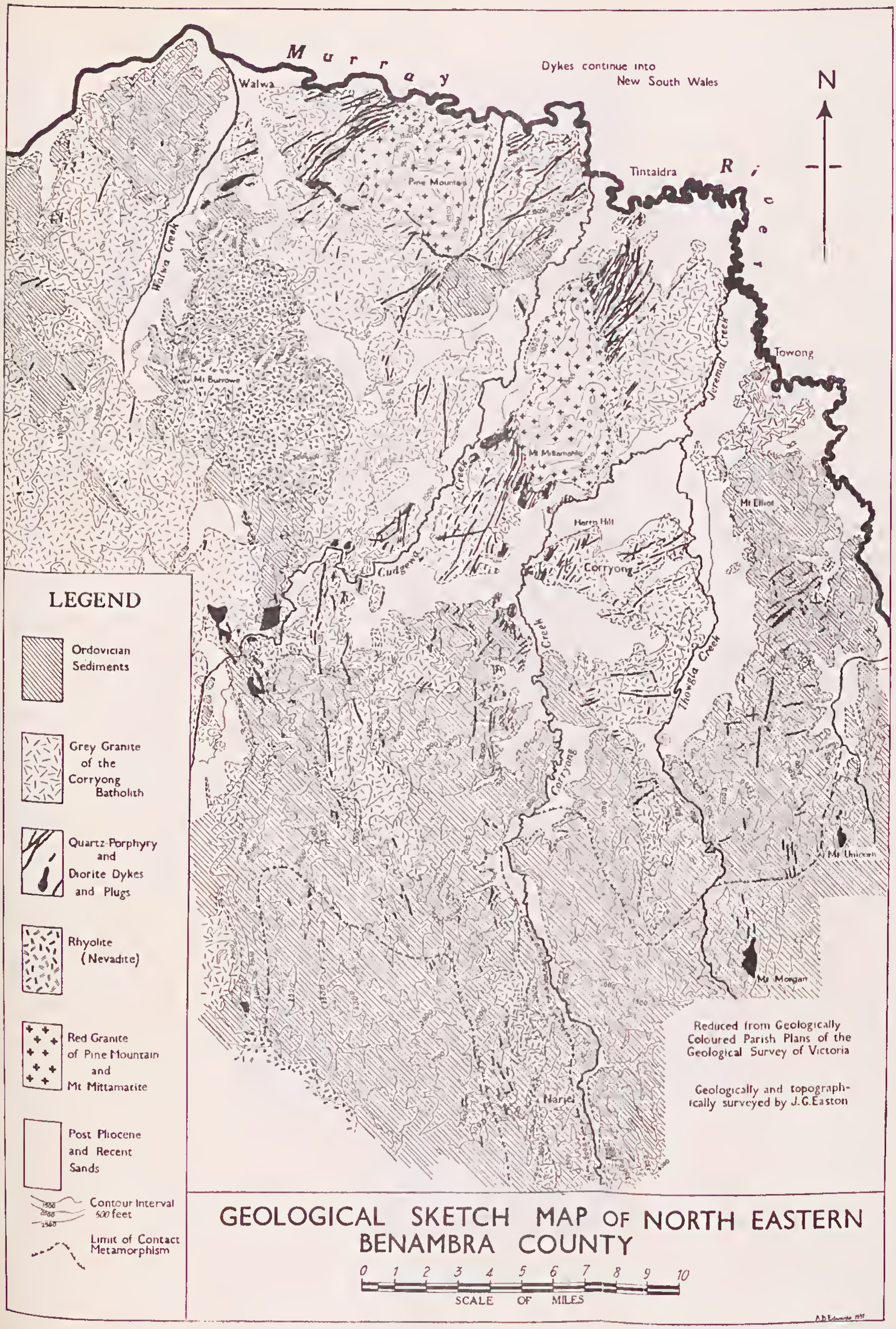
Drainage.

The Murray River dominates the drainage system of the region. Where it enters the area, near the south-eastern corner of the Parish of Thowgla, its valley opens out from a gorge tract (some 25 miles in length), into wide alluvial flats. It takes a northerly course until opposite Tintaldra township, when it bends to the west in a right angle. After passing through the township, it swings sharply again to the north, and continues in that direction for several miles, before taking another right-angle bend to the west. From thence it follows a winding course along the northern boundaries of the Parishes of Walwa and Burrowye, with an average fall of about 3 feet to the mile. It is flanked by rich flats of varying width, at about 700 feet above sea level, which give place inland to increasingly mountainous country.

The tributaries joining the Murray in this part of its course (from the Victorian side), are the Biggera, Jeremal, Cudgewa, Pine Mountain, and Walwa Creeks. The principal of these are Cudgewa Creek, and the two branches of Jeremal Creek, the Thowgla, and Corryong Creeks.

As will be seen from the map (Fig. 1), in the southern parts of their courses these streams flow through Upper Ordovician sediments, and their courses are more or less parallel to the W. of N. strike of the sediments. About the middle of the area, however, they pass from a region of contact metamorphosed sediments into granitic rocks. As a consequence the direction of their courses becomes about 20° E. of N., parallel to the strike of the prevailing joints in the granites, and to the general strike of the quartz-porphyry and diorite dykes which have invaded the granite. This indicates that the present drainage system has developed subsequently to a peneplanation of the whole area and that the granitic rocks of the northern part must have been exposed before it originated.

Consideration of a wider tract of country shows that streams to the east of the area under discussion flow in a north-easterly direction to the Murray (Indi), while streams to the west flow to the north-west. The drainage pattern of Benambra is, therefore, more or less fan-shaped, with a central core of high



Murray River
Dykes continue into New South Wales
N
Walwa
Pine Mountain
Tintaldra
Walwa Creek
Mt Burrowe
Towong
Jeremal Creek
Mt Mittamatite
Mt Elliot
Harris Hill
Cudgewa Creek
Corryong
Corryong Creek
Thowgla Creek
Mt Unicorn
Mt Morgan
Nariel
Reduced from Geologically Coloured Parish Plans of the Geological Survey of Victoria
Geologically and topographically surveyed by J.G.Easton
LEGEND
Ordovician Sediments
Grey Granite of the Corryong Batholith
Quartz-Porphyry and Diorite Dykes and Plugs
Rhyolite (Nevadite)
Red Granite of Pine Mountain and Mt Mittamatite
Post Pliocene and Recent Sands
Contour Interval 500 feet
Limit of Contact Metamorphism
GEOLOGICAL SKETCH MAP OF NORTH EASTERN BENAMBRA COUNTY
0 1 2 3 4 5 6 7 8 9 10
SCALE OF MILES

Fig. 1

8548.

mountains in the vicinity of Mt. Gibbo (5,763 feet). The immaturity of the streams indicates that the dissection of the pene-plain has occurred recently. It probably began with the Kosciusko uplift, during the Pliocene (2, p. 91).

Individual Streams.

The Jeremal Creek, which enters the Murray below Towong, (see map) is the largest and longest of the tributaries. It consists of two branches, the Thowgla and Corryong Creeks, which junction about 5 miles above its mouth. The Thowgla, or eastern branch, rises well south of the area, at Mt. Pinnibar (4,100 feet), and the Corryong, or western branch, at Mts. Pinnibar and Gibbo. For about 40 miles they flow in narrow valleys through steep, often precipitous, country. Below Nariel township site, alluvial flats from one quarter of a mile to a mile wide occupy the valley of Corryong Creek. Below Corryong township these flats become still more extensive. Similar flats extend for about 12 miles up Thowgla Creek.

East of Thowgla Creek is Biggera Creek, only 8 miles long. It rises to the east and west of Mt. Unicorn, and flows with a gentle gradient through normal and slightly metamorphosed Ordovician slates and sandstones to the Murray (Indi) River.

Cudgewa Creek, to the west of Jeremal Creek, rises at Mt. Cudgewa (3,575 feet) in the Parish of Canabore (outside the western limit of the map), and flows north-easterly through granitic country for about 30 miles, joining the Murray below Tintaldra township. It has its source in an alluvial flat of about 60 acres extent, near the summit of the range, at the contact of granite and metamorphic rocks, and falls 900 feet in a distance of three-quarters of a mile, over a series of cascades, before taking a winding course, with intermittent flats and terraces in its upper reaches. From Lucyvale it flows northerly for about 5 miles to Berringama through a fairly wide valley in the granitic rock. There it enters a gorge winding between steep hills, as far as Cudgewa, where the valley widens and flats have developed, which continue until they reach the Murray.

Walwa Creek drains the northern and western slopes of Mt. Burrowye (4,181 feet) a great mass of rhyolite. Its two main branches rise on the eastern and western slopes of this prominent landmark, and converge in gullies, towards Walwa township. Their valleys widen as they pass from the rhyolite into the lower, undulating granite and sedimentary country about the township. The united stream joins the Murray immediately below the township. The total length of the stream, which rises at 4,000 feet, and enters the Murray at about 700 feet above sea-level, is not more than 10 miles.

Between Walwa and Cudgewa Creeks is the short Pine Mountain Creek, which rises at the southern base of the more or less conical mountain of red granite known as Pine Mountain, and flows along the junction of this granite with the earlier, and lower level grey granite, to the Murray.

Mountains and Ranges.

The dissection of the original peneplain into a system of spurs and mountains with innumerable lateral gullies has been further diversified by the presence, especially in the northern part, of a number of conspicuous monadnock features. The main ridges have a northerly trend, and form interfluves between the creeks. Like the creeks they radiate more or less from Mt. Gibbo. The Indi-Thowgla divide, beginning at Mt. Gibbo, and connecting with Mt. Pinnibar, continues in a northerly direction as a series of knobs and saddles gradually decreasing in altitude, with lateral spurs dropping off into the adjoining valleys. The interfluve is formed chiefly of Ordovician sediments, as far as Mt. Elliot, a prominent point 3,000 feet above sea-level, about 4 miles east of Corryong township. There it drops off suddenly into softer granitic rocks, terminating at Towong on the Murray River. The summit of the range is about 1 to 5 chains in width.

West of this is a subsidiary ridge forming the interfluve between the Thowgla and Corryong Creeks. This is a spur which branches off the main Indi-Thowgla ridge at Mt. Pinnibar. It consists of a series of peaks and saddles trending practically due north, and terminating at Corryong. Two of the saddles form conspicuous gaps—Nariel Gap and Green Wattle Gap.

The range forming the western interfluve of Corryong Creek is a branch of the main range which begins in the vicinity of Mt. Gibbo, and follows a north-westerly course towards Mt. Cudgewa. This range trifurcates near the northern head of the Dark River (south of the map). The eastern branch runs almost due north, parallel to the Corryong Creek, to the Colac Colac-Corryong Gap. Mt. Mittamatite, and its erosion shadow, serve as a continuation of this interfluve between the Cudgewa and Jeremal Creeks. The main branch continues beyond Mt. Cudgewa to the vicinity of Shelley railway station, where it bifurcates. The eastern bifurcation connects with Mt. Burrowye, and forms the interfluve between Walwa and Cudgewa Creeks. Between the head of the Dark River and Mt. Cudgewa, the main divide sends off an important spur to Mt. Benambra (4,843 feet), an extensive mass of rhyolite, similar to Mt. Burrowye.

Monadnocks.

The Mt. Benambra rhyolite mass, which just appears in the southern part of the map (Fig. 1), is one of the monadnocks. Other conspicuous monadnocks are Mt. Burrowye, Mt. Mittamatite, and Pine Mountain, in the northern part of the area.

Mt. Burrowye (4,194 feet) is a mass of rhyolite. It rises up like a massive fortress, in a series of cliffs and precipitous slopes, edged with screes, above the surrounding hills of granite and Ordovician sediments. The summit is a dissected plateau. Pronounced jointing can be seen, especially on the north-eastern side, where two well-defined systems of joints strike at N. 60° W. with a dip of 80° N.E., and N. 30° E. with a dip of 65° S.E. The main creeks in this formation conform to the N.E. joints, while the small lateral creeks follow the N.W. set.

Mt. Mittamatite and Pine Mountain are more or less conical bosses or cupolas of red granite, which stand out above the adjacent grey granite. Mt. Mittamatite has a well-defined erosion shadow to the N.E. of it.

There are in addition several smaller and less prominent monadnocks. Mt. Morgan (3,450 feet), east of Thowgla Creek, in the southern part of the area, and Mt. Unicorn (2,910 feet) 5 miles N.E. of it, form noticeable peaks. Both are plugs of quartz-porphyry, surrounded by indurated Ordovician sediments. A number of other small hills, in the Corryong District are also of this character, e.g., Harris Hill, Playle's Hill, and Mt. Sugarloaf. These have withstood erosion owing to the fact that they are traversed by quartz-porphyry and diorite dykes which are harder than the surrounding sediments. The extra hardness of the dyke rocks, both here and elsewhere, has caused the dykes to stand out as walls across the country.

General Geology.

1. Upper Ordovician Sediments.

The oldest rocks exposed in the area are folded sediments of Upper Ordovician age. Their greatest development is in the eastern and southern parts. They consist of drab yellow, brown and black slates and shales, with siliceous and felspathic sandstones, and occasional grit beds. Grits and sandstones, composed of quartz and felspar fragments, with some inclusions of black slate are prominent in the Parish of Thowgla, and can be traced for several miles along their strike, which is N. 20–30° W. The folding is open where the beds are competent, with perhaps two anticlines and synclines to the mile; but where the sediments are finely bedded, much closer folding has developed. Marked pitch makes the apparent strikes variable.

Some of the slates are carbonaceous, and contain graptolites. At Reedy Creek these graptolite slates are about 10 chains in width, and graptolites occur in them over a length of 2 miles along the strike. The collections made by Mr. Easton from here, and from other localities within the area have not, as yet, been specifically determined. Earlier collections made by W. H. Ferguson, however, from these and other localities in this region have been examined by the late T. S. Hall, and are classed as Upper Ordovician (14, 15).

After being folded, the sediments were intruded by a granitic batholith. Prolonged erosion has deroofed the higher parts of the batholith, while elsewhere it has reduced the sedimentary cover to a thin metamorphosed roof. An excellent illustration of the effect and degree of the contact metamorphism is afforded by the steep range to the east of Thowgla Creek, in the Parish of Thowgla. Going eastwards from the more easily weathered granite, in which the Thowgla Creek has cut its valley, and which is now hidden under alluvium, across the steep ridge which marks the contact aureole, the succession is from highly micaceous schists to andalusite schists, which grade out into spotted schists containing embryo crystals. These, by degrees lose their nodular appearance, becoming more micaceous, and give place to lustrous phyllites, until, at about a mile from the hidden contact, the strata are normal slates and sandstones. This, of course, gives no indication of the true width of the contact zone, owing to the gentle slope of the underlying granite surface. The true thickness is more adequately indicated by the height of the ridge above the creek level, which is about 500 feet.

Roof pendants, and large xenolithic blocks occur wherever the deroofing of the granite rocks has been only recently accomplished.

2. Igneous Rocks.

Igneous rocks outcrop over a large part of the area, being concentrated in the northern and western parts. They belong to two distinct periods of intrusion (25, p. 107), both later than the folding of the sediments. There are several facies to each period, and their order of intrusion is fairly clearly defined.

(i) *The Corryong Grey Granite.*

The earliest, and most extensive, of the igneous intrusions is a batholith of grey granite which underlies most, if not all, of this part of Benambra, and extends beyond into New South Wales, and Northern and Eastern Victoria for undetermined distances. It is a grey biotite granite, which varies in texture from a fine-grained to a fairly coarse-grained porphyritic rock, with large phenocrysts of felspar. At Corryong it verges on granodiorite, but in other districts, as at Koetong (27, p. 21) is a granite. The rock from Mt. Cudgewa, on the other hand, has been described as granodiorite (3, p. 96). It is always easily distinguished, however, from the later granites proper, both by its appearance, and its chemical composition (see p. 82).

The age of this great intrusion cannot be fixed; but it is assumed that it developed as an aftermath of the (?) Lower Devonian orogeny, during which the sediments were folded.

During the later stages of cooling of this batholith, or subsequently, a series of stanniferous pegmatites and greisens and quartz veins were formed contiguous with its contacts. These occur conspicuously at Walwa (7, 8), Koetong (3), and Mt. Cudgewa (3, 6). Frequently they are rich in tourmaline, as well as cassiterite, and scheelite (9) is developed locally. In the Corryong-Thowgla region these pneumatolytic deposits are replaced by gold-pyrite veins (representing the transition to hydrothermal conditions) (5), and traces of copper (5); while in the neighbourhood of Pine Mountain, hydrothermal lodes of silver-bearing galena and fluorite occur (4). These, however, may be associated with the subsequent red granite of Pine Mountain, since these granites and their associated dykes are rich in both fluorite and tourmaline.

(ii) *Later Granitic Intrusions.*

The second period of igneous activity gave rise to a more limited, but more complex series of contemporaneous intrusions. These, in the apparent order of their development, are:—(*a*) a dyke swarm. (*b*) an extrusion of rhyolite. (*c*) intrusion of two granitic bosses, or cupolas, and associated dykes.

(*a*) *The Dyke Swarm.*

The second period of activity opened with the intrusion of a swarm of acid and intermediate dykes into the Corryong grey granite, and the Ordovician sediments. Approximately 850 dykes have been mapped in this area, and similar dykes occur, though less profusely throughout the County of Benambra (23, 27, 29). Of those mapped, about 50 are granitic dykes, 500 are of quartz-poprhyry, and quartz-felspar-hornblende-porphyrite, and about 300 are of quartz-diorite. These figures do not adequately indicate the predominance of the quartz-porphyry dykes, since they take no account of relative size. The individual granite and diorite dykes can rarely be traced over distances much greater than a mile. The quartz-porphyry dykes, on the other hand, are frequently over a mile in length, and some have been traced in outcrop for over 4 miles. Also they are generally wider than the other types, and show bulges along their strike. Occasionally the quartz-porphyries form plugs. Two such plugs, Mt. Morgan and Mt. Unicorn, stand out as prominent hills. Mt. Morgan forms a peak 3,450 feet above sea level in the Parish of Kancobin. It consists of a central core of quartz-porphyry surrounded by contorted and indurated Ordovician sediments, which indicate that it was intruded under considerable pressure. About 5 miles to the N.E. on the southern boundary of the Parish of Thowgla is Mt. Unicorn, 2,910 feet above sea level, with a similar core of quartz-porphyry surrounded by silicified sediments.

The order of intrusion of the dyke types is from acid to basic, as is clearly shown in Fig. 2, which illustrates the occurrence of three dykes of different type in allotment 81, Parish of Cudgewa. It is not certain whether the granitic dykes belong to the dyke swarm, or are a final product of the earlier igneous activity. They are closely associated with the quartz-porphyry dykes in several localities, but, as shown in Fig. 2, the quartz-porphyry and quartz-diorite dykes fill fissures and fractures which have displaced the granite dykes as much as 100 feet laterally.

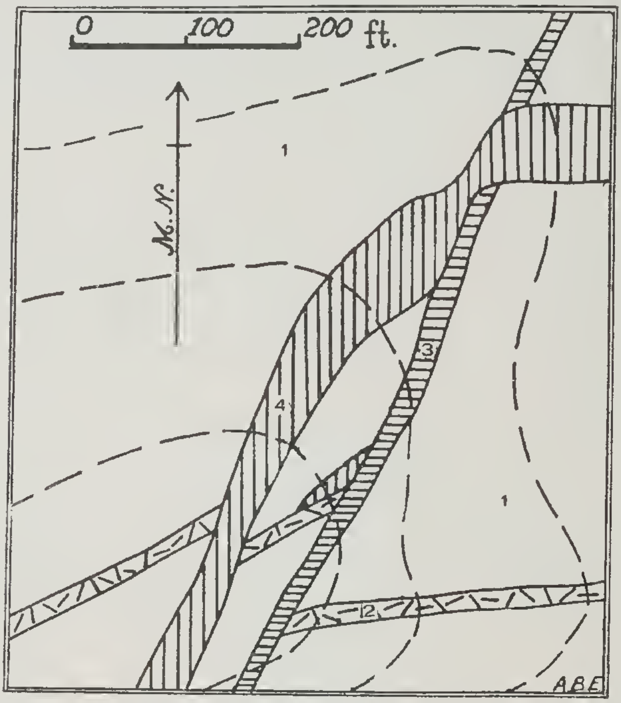


Fig. 2. Dyke Sequence in Allotment 81, Parish of Cudgewa. 1. Grey Corryong Granite. 2. White Granite Dyke. 3. Granophyric Quartz-Porphyry Dyke. 4. Quartz-diorite Dyke.

The diorite dykes intrude the quartz-porphyry dykes, but frequently they have risen up the same channel, since they occur as parallel or composite dykes, often along the contact of the quartz-porphyry dykes and the wall rock. Occasionally they bulge, like the porphyries. Two of the largest outcrops are in allotment 8, section VI., Parish of Wabba, and in the basin of a big gully east of Scammel's homestead, on Thowgla Creek, where a coarsely crystalline diorite occupies an area of about 30 acres.

The strike of the dyke swarm appears to have been controlled by pre-existing structures in the Corryong granite, and in the Ordovician sediments. In the granitic areas, and within the shallower parts of the contact aureoles, the strike of the dykes is generally between N. 30° E. and N. 60° E. corresponding with a strong jointing direction in the granite. Outside the contact aureoles the dykes are parellel to the strike of the invaded Ordovician, and strike more or less N. 30° W.

There are marked concentrations of the dykes, one in Walwa, centred about the later granitic intrusion of Pine Mountain, and the other in Tintaldra and Colac Colac, centred about the similar later granite intrusion of Mt. Mittamatite (Fig. 3). In these

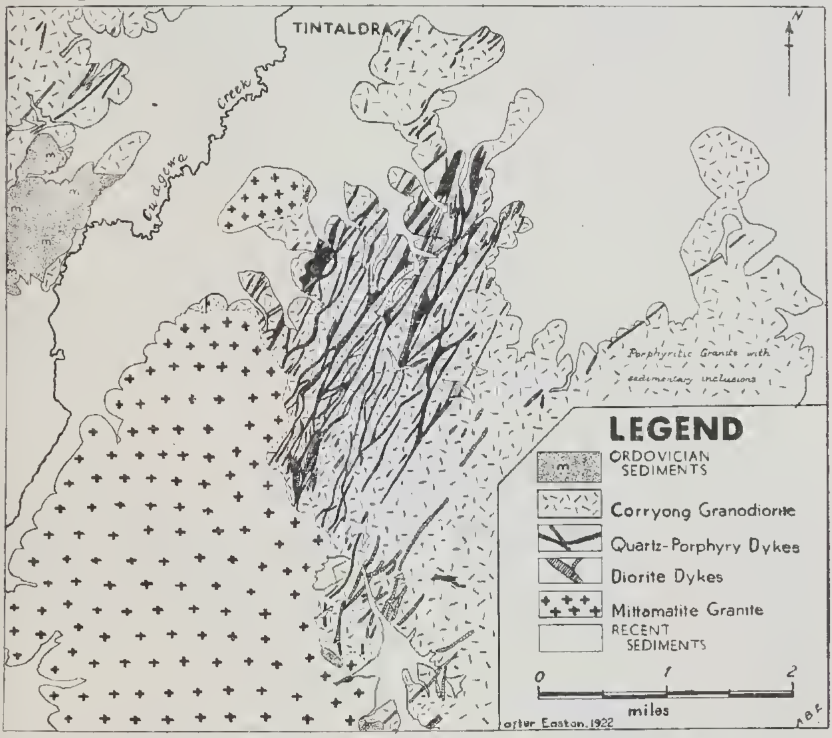


Fig. 3. "Dyke Stockwerk" on the N.E. slopes of Mt. Mittamatite.

two regions the swarm becomes more or less a "dyke stockwerk". The individual dykes branch and rejoin and lie at all angles to the vertical, up to 90°. It is further noticeable that while the quartz-porphyry dykes are found practically throughout the whole area, the diorite dykes are more or less limited to the vicinity of these intrusions. There are numerous exceptions.

This concentration of dykes in association with the later granite, of composition identical with that of the acid dykes, suggests a close magmatic and structural relation.

In the southern part of Towong, the strike of the dykes approaches nearer east-west, while a subsidiary group strike parallel with the strike of the sediments. Still further south, in Thowgla, the quartz-porphyry dykes strike with the sediments, while later dioritic dykes cut them more or less at right angles.

(b) The Jemba Rhyolite.

Subsequent to, or possibly contemporaneous with, the intrusion of the dykes, a flow or flows or rhyolite (nevadite), totalling over 2,000 feet in thickness, was extruded and covered almost all of what is now the Parish of Jemba. The rhyolites extend northwards some distance into the Parish of Walwa, where there are some very broad quartz-porphyry dykes close to their boundary, and eastwards into the Parishes of Cudgewa and Tintaldra, forming an irregularly elliptical mass of rhyolite of about 25 square miles area, with its longer axis striking west of north.

Along its eastern and north-western boundaries the rhyolite rests on the exposed surface of the Corryong granite, and along its western and southern edge, and in the extreme north, it overlies an erosion surface of contact-metamorphosed Upper Ordovician sediments, and occasionally what appear to be river gravels, as in allotment 39, Parish of Jemba (the S.W. side), and allotment 56, Parish of Cudgewa (the N.E. side). The gravels consist of water worn, and angular, pebbles of hard black slate, quartzite, and a hard flinty rock enclosed in granite. Mount Burrowye, the highest point, is 4,194 feet above sea-level, and several other peaks are over 4,000 feet.

The base of the rhyolite, so far as can be ascertained from the level of its boundaries, is uneven. It averages between 2,000 feet and 2,500 feet above sea-level, but on the north-western side it is as low as 1,500 feet above sea-level. Since the later granite rocks of Pine Mountain and Mount Mittamatite intruded to levels at least 1,300 feet above the base of the rhyolite, and the rocks to the west are still of higher level than the rhyolite base, it is evident that the rhyolite was extruded into a valley or basin-like erosion structure, whose outlet was to the north-west.

This indicates that localized erosion accomplished as great a degree of unroofing of the Corryong granite in such time as elapsed between the (?) Lower Devonian orogeny and the second period of igneous activity, as has all the erosion that has gone on in the area since. This "fossil basin" or Devonian deep lead which has been preserved by the rhyolite extrusion, indicates that enormously greater erosive forces were at work immediately subsequent to the orogeny, than in later times; and the fact that this erosion uncovered part of the Corryong granite is evidence that the intrusion of this batholith did concur with, or develop immediately after the orogeny.

(c) Red Granites of Pine Mountain and Mt. Mittamatite.

The final stage of the second period of igneous activity was the intrusion of two stocks or cupolas of red granite through the Corryong grey granite, and the dyke swarms, for some hundreds of feet into the sedimentary cover above. These two stocks now stand out as prominent, steep-sided, more or less conical hills, Mt. Mittamatite (3,340 feet) and Pine Mountain (3,310 feet), and support a flora different from that of the adjacent grey granite. Mt. Mittamatite is more or less elliptical in cross-section, the long axis of the ellipse being parallel to the strike of the dyke swarm.

No dykes exist within either of these masses, and all the pre-existing dykes are cut off abruptly at the contact, but a number of red porphyry dykes of the same age as the granites radiate out into the network of other dykes. Some of these are not easily discriminated from the indurated older dykes near the contact. Occasional outcrops of similar red porphyry dykes occur in other parts of the area.

3. *Post-Pliocene Deposits.*

Remnants of old creek beds occur at several localities, as between Lucyvale and Berringama, where they form small cappings on the low granite spurs. Similar deposits are found west of the present area, and have been worked for their tin and gold content.

More recent alluvium forms flats along the lower reaches of most of the streams, and on either side of the Murray River.

Petrology.

1. The Corryong Granite.

The Corryong granite is a medium-grained grey rock, grading locally into a porphyritic phase, in which large phenocrysts of orthoclase, an inch or more in length, are prominent. The minerals constituting it are quartz, orthoclase and oligoclase (Ab_{75}) in about equal proportions, a little microcline and vein-perthite, abundant biotite, muscovite, and coarse prisms of apatite. The plagioclase is sometimes zoned, the core zones consisting of acid andesine. Occasionally it occurs as idiomorphic tabular crystals with rims of orthoclase. Myrmekite intergrowths are abundant. The biotite is almost uniaxial, and is pleochroic from pale yellow or pinkish-yellow to rusty red-brown, so that it is an iron-magnesia- rich variety. In places it is intergrown with green or white muscovite.

Where the granite is porphyritic, it is frequently much contaminated with sedimentary xenoliths, e.g., in the vicinity of Wermatong, Parish of Tintaldra, it contains a prolific number of partially digested xenoliths.

Examination of the chemical analyses of Victorian granitic rocks shows that they fall into three well defined groups, granites proper, granodiorites proper, and an intermediate group, whose character is most nearly indicated by the now discarded name "adamellite" (26). A chemical analysis of the Corryong granite (Table 1, No. 1), shows that it has a composition comparable with this third group of Victorian granites, which verge

TABLE I.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	—
SiO_2	67·67	68·92	75·98	74·67	67·72	50·79	49·65	46·90	76·60	74·28	74·80	SiO_2
Al_2O_3	14·50	16·21	12·75	12·18	13·62	16·40	16·73	16·54	12·14	12·90	12·53	Al_2O_3
Fe_2O_3	0·87	0·57	0·58	1·56	0·88	2·11	0·31	4·66	1·01	1·16	1·02	Fe_2O_3
FeO	3·78	2·42	0·65	1·03	2·44	6·26	8·99	9·19	0·26	1·04	0·91	FeO
MgO	2·21	1·04	tr.	tr.	1·39	5·68	5·88	7·29	tr.	tr.	tr.	MgO
CaO	2·18	2·31	0·68	1·04	2·91	8·31	7·87	10·32	0·49	1·12	0·78	CaO
Na_2O	2·38	2·43	3·15	3·28	3·04	3·42	3·10	2·59	3·29	2·96	3·06	Na_2O
K_2O	3·42	4·36	5·47	5·34	3·64	1·37	0·80	1·36	5·26	5·32	5·95	K_2O
H_2O + ..	1·81	0·93	0·40	0·32	1·65	3·59	2·50	0·55	0·71	0·78	0·81	H_2O +
H_2O − ..	0·11	0·08	0·04	0·07	0·26	0·28	0·14	0·15	0·09	0·07	0·14	H_2O −
CO_2	tr.	..	tr.	Nil	1·95	0·30	1·08	tr.	tr.	tr.	tr.	CO_2
TiO_2	0·61	0·52	tr.	tr.	0·45	1·43	2·81	0·52	tr.	0·17	0·21	TiO_2
P_2O_5	tr.	0·30	Nil	tr.	tr.	tr.	0·04	0·02	Nil	tr.	tr.	P_2O_5
MnO	tr.	0·03	tr.	0·03	tr.	tr.	0·14	0·03	tr.	tr.	tr.	MnO
Cl	tr.	..	tr.	..	tr.	tr.	..	..	tr.	tr.	tr.	Cl
FeS_2	Nil	tr.	Nil	..	Nil	0·34	..	..	Nil	Nil	Nil	FeS_2
SO_3	Nil	..	Nil	..	Nil	Nil	..	..	Nil	Nil	Nil	SO_3
Total ..	99·54	100·12	99·70	99·52	99·95	100·28	100·04	100·12	99·85	99·80	100·21	Total

1. Grey biotite granite, E. of Allot. 8, Sect. VII., near contact, Parish of Cudgewa. Analyst—F. F. Field. [G.S., 1907.]
2. Granite, Koetong Mass, Tallangatta-Granya road. Analyst—C. M. Tattam. [Bull. Geol. Surv. Victoria, No. 52, 1929, p. 38.]
3. Rhyolite from Mt. Burrowye, Parish of Jemba. Analyst—F. F. Field. [G.S. 1914.]
4. Quartz-porphyry dyke, Allot. 56 of Cudgewa. Analyst—A. B. Edwards. [M.U., 2150.]
5. Quartz-felspar-porphyrite, dyke at Tintaldra bridge, Parish of Tintaldra. Analyst—F. F. Field. [G.S., 2097.]
6. Quartz-augite-diorite, Harris Hill, Allot. 4B, Parish of Colac. Colac. Analyst—F. F. Field. [G.S., 2098.]
7. Propylitized diorite porphyrite, Morning Star Dyke, 10 feet from Cherry's reef, Hope adit level. Analyst—N. R. Junner. [Proc. 39, Aust. Inst. Min. Met., 1920, p. 188.]
8. Labradorite-porphyrite dyke, Allot. 4, Sect. 6, Parish of Tintaldra. Analyst—A. B. Edwards. [M.U., 2157.]
9. Red granite from Pine Mountain Creek, Parish of Cudegwa. Analyst—F. F. Field. [G.S., 2101.]
10. Red granite from Mt. Mittamatite, Allot. 69, Parish of Towong. Analyst—F. F. Field. [G.S., 2099.]
11. Red porphyry dyke, N. boundary of Allot. 8, Sect. VIII., Parish of Walwa. Analyst—F. F. Field. [G.S., 2100.]

on granodiorite. The composition varies somewhat in other parts of the batholith. Thus Tattam (27, pp. 21, 38) has described outcrops of the porphyritic variation at Koetong as normal granite, but as will be seen from Table 1, the analysis of the Koetong granite resembles that of the Corryong granite in its SiO_2, CaO, and Na_2O contents much more closely than it resembles the true granites (Nos. 9, 10). The higher Al_2O_3, SiO_2 and K_2O correspond to the development of large phenocrysts of orthoclase. The Yackandandah granite (27, p. 38) is also of this variety. Mahony, on the other hand, has described the rock from Mt. Cudgewa as a granodiorite (3, p. 96). The Corryong granite, however, is as distinct from the Victorian granodiorites proper as it is from the granites proper.

2. The Jemba Rhyolite (Nevadite).

In hand specimen the rhyolite varies in appearance from a pinkish-red rock, studded with small glassy phenocrysts of quartz, to a brownish-grey rock speckled with pink crystals of microperthite and glassy quartz crystals. Fragmental facies, in which the rhyolite is crowded with small angular fragments of hornfels, are common.

In thin section the phenocrysts are found to consist of quartz, perthitic orthoclase, subordinate acid plagioclase, a little biotite, and occasional tourmalines, set in a microcrystalline groundmass of quartz and felspar, which occasionally shows granophyric or spherulitic textures.

The quartz phenocrysts occur as doubly terminated rhombohedra which are deeply embayed. They may be as large as 2 to 3 mm. in diameter, and contain inclusions of sphene and fine rods of (?) apatite. They are perhaps the most abundant phenocrysts.

The orthoclase occurs as rounded, sometimes embayed, crystals. It is frequently brownish from the presence of iron oxide, which forms vaguely defined bands parallel to the cleavage, and is responsible for the pink colour of the felspar in hand specimen. Much of the orthoclase contains microperthite, both ex-solution perthite in fine parallel lamellae, and vein-perthite. In some crystals a transition from one type of perthite to the other can be observed. These orthoclase crystals are invariably edged with a narrow ragged rim of clear, non-perthitic orthoclase, in optical continuity with the crystal as a whole, and probably developing during the general crystallization subsequent to extrusion. The crystals show simple Carlsbad twinning, and not infrequently enclose areas of acid plagioclase. Such plagioclase inclusions often have a partially sericitized core. Phenocrysts of plagioclase are subordinate to orthoclase. They consist of oligoclase (Ab_{80}), showing a maximum symmetrical extinction angle of about 5°, and rarely zoned.

Biotite is present as occasional longitudinal crystals, which are frequently bent or crushed. It is often partially bleached or chloritized, and has precipitated grains of iron oxide. Many of the crystals are fringed with granules of tourmaline. The tourmaline also occurs as crystals as large as the biotite, or as granular aggregates. Blue, green, and brown varieties occur, the blue being the more usual. Sometimes it occurs as a fringe about sporadic crystals of pyrrhotite. Minute trigonal crystals occur throughout the groundmass, and are often concentrated in small clusters in the embayments of the quartz phenocrysts (cf. 16, p. 189).

Microscopically, and chemically (Table I, No. 3), the Jemba rhyolite closely resembles the nevadite rhyolites of Taggerty (16), and Narbethong (20). It is slightly more acid than these, but the most distinctive difference is the apparent absence of cordierite from the Jemba rhyolite. It equally resembles the rhyolite (or quartz-porphyry) mass of Mt. Benambra, to the south of the area under discussion. Chemically it is almost identical with the more common type of quartz-porphyry dykes of the dyke swarm, and with the red granites of Pine Mountain and Mt. Mittamatite and their related red porphyry dykes; and it resembles them still further in its content of clouded orthoclase, vein-perthite, and tourmaline.

3. Granitic Dykes.

The earliest members of the dyke swarm are granite dykes, not easily distinguished in hand-specimen from the red granites of Mt. Mittamatite and Pine Mountain, and aplites.

(i) *The Granites.*

The granite dykes consist of quartz, microperthite, orthoclase, subordinate oligoclase, and biotite, sometimes with a small amount of coarse-grained groundmass of quartz and felspar. Orthoclase with vein-perthite is the dominant felspar, and it is strongly clouded with particles of iron oxide dust, which gives it a pinkish colour in the hand-specimen. The plagioclase is sericitized and occurs both as large crystals, and as numerous inclusions in the orthoclase and microperthite. The biotite is pleochroic from yellow to deep green, and is sometimes partially chloritized. In some dykes its place is taken by colourless muscovite. Occasionally patches of tourmaline, and more rarely crystals of orthite and cassiterite, are seen.

(ii) *The Aplites.*

The aplites are microporphyritic, with idiomorphic crystals of quartz, less numerous orthoclase, and large plates of muscovite, set in a coarsely granular groundmass of quartz, orthoclase, and slightly larger crystals of oligoclase. The quartz and orthoclase phenocrysts contain numerous inclusions of the groundmass minerals. Generally these are scattered throughout the crystals, but in some quartz phenocrysts there is a tendency for them to be arranged zonally.

4. Quartz-porphyry Dykes.

These, the most abundant among the dykes, may be sub-divided into two groups:—

(i) *Quartz-felspar-porphyries, and Granophyres.*

These are light coloured, buff or brown, sometimes grey, rocks, consisting of phenocrysts of quartz and pink felspar, with occasional small clots of biotite or sheaves of green hornblende, set in a microcrystalline groundmass of quartz, orthoclase, sometimes biotite, and subordinate tourmaline. The relative proportions of the quartz and felspar phenocrysts are variable. The phenocrysts are invariably embayed, the embayments usually containing small aggregates of minute tourmaline granules.

The felspar is mostly orthoclase, or vein microperthite, cloudy or brownish from the presence of iron oxide dust. Subordinate oligoclase (Ab_{70}) is generally preseut, and frequently is sericitized.

Ferromagnesians are generally absent; but when present they consist of decussate sheaves of biotite, pleochroic from faint yellow to foxy red, or, more often, clusters of minute sheaves or prisms of green hornblende. The hornblende has an extinction angle of 16°, and is pleochroic with X = green, Y = straw yellow, Z = blue green. It is altering (fig. 4, C) to biotite and iron ore, and the derived biotite flakes show a decussate structure with two sets of sheaves more or less parallel to the original hornblende cleavages. The iron ore thrown out from the hornblende forms into crystals, and the biotite flakes frequently centre about

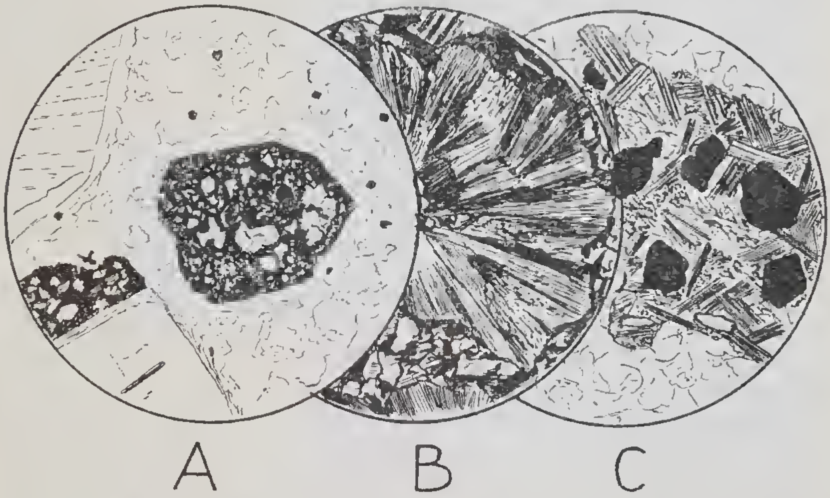


Fig. 4. A. Micro-"quartz-tourmaline nodule" in quartz-porphyry. × 200.
B. Micro-spherulitic growth in groundmass of quartz-porphyry. × 200.
C. Hornblende altering to biotite and iron ore in quartz-porphyry. × 200.

these crystals. Sometimes, however, the biotite appears to develop as a result of a reaction of the iron ore with the groundmass, as described by Richards (24) and Edwards (10).

The groundmass varies from coarse to finely microcrystalline, and in some instances is micro-spherulitic (fig. 4, B). More often it is a more or less granophyric intergrowth of quartz and orthoclase. Tourmaline is present in almost every section, mostly as the blue or brown variety, but sometimes as the green variety. In one section "micro-quartz-tourmaline nodules" are abundant (fig. 4, A). These consist of single crystals of blue tourmaline, poecilitically enclosing numerous quartz grains. Sometimes they possess a prismatic outline, but more frequently the outline is rounded. These structures appear to be equivalent on a microscale to the quartz-tourmaline nodules found in granites (12); and they probably represent bubbles of boron which formed in the rock during its intrusion, and reacted with the orthoclase felspar to form the blue potash-rich variety of tourmaline as the groundmass of the rock chilled.

In general appearance these rocks closely resemble the Mt. Burrowye rhyolite, particularly in the matter of the cloudy red microperthite phenocrysts, and the common presence of tourmaline. Chemically (Table 1, No. 4) they are identical with the Mt. Burrowye rhyolite, and with the red granites of Mt. Mittamatite and Pine Mountain, and their subsequent red porphyries.

(ii) *Quartz-felspar-hornblende-porphyrites.*

Dykes of this sub-group are easily recognized in the hand specimen. They are grey-green rocks, plentifully studded with glassy grey quartz phenocrysts, as large as 4 mm. across, whitish-grey felspars, and spots of blackish-green ferromagnesians, set in a dense grey groundmass which is spotted with greenish calcitized patches. Sometimes in addition, as in the dyke at Tintaldra Bridge, they contain megaphenocrysts, often 10–15 mm. in diameter, of pink orthoclase. In the absence of these the rocks closely resemble the quartz-dacite (rhyodacite) of Maroondah Dam, Healesville (10).

In thin section they consist of phenocrysts of quartz, felspar and altered hornblende, set in a micro-crystalline or granophyric groundmass of quartz and orthoclase, and sometimes tourmaline.

In the Tintaldra Bridge dyke, which has been propylitised, the hornblende phenocrysts are completely altered to composite pseudomorphs of chlorite (penninite), calcite, and apatite, which frequently retain the idiomorphic outline of the hornblende. The felspar is all altered to sericite, the biotite is chloritized, and pyrrhotite has been introduced. The normal alteration of the hornblende is to decussate sheaves of biotite and granules of quartz, which also still preserve to some extent the outline of the original hornblende crystals. Small flakes of a later green hornblende are sometimes developed. In other instances the original hornblende has been replaced by aggregates of small hornblende crystals, pleochroic with X = pale yellow, Y = green, Z = blue-green. Both types of replacement may occur in the same slide.

In addition to the clusters of decussate biotite, larger, ragged-ended flakes of biotite can be found, possibly formed by the coalescence of such sheaves. The quartz and the felspar generally form embayed, composite phenocrysts; and both may be present in the same clot. The individual crystals in the clots are generally allotriomorphic and interlocked. When the large pink, clouded orthoclase phenocrysts are not developed, the dominant felspar is oligoclase (Ab_{70}). In one specimen a xenocryst of quartz is present surrounded by a reaction rim of green hornblende.

Mineralogically and chemically the rocks of this group are intermediate between the quartz-felspar-porphyries and the hornblende-diorite-porphyrites. The analysis of the Tintaldra Bridge dyke (Table 1, No. 5) closely resembles that of the grey Corryong granite.

5. Diorite-porphyrite Dykes.

The diorite-porphyrite dykes are readily distinguished in hand specimen from the more acid varieties by their green, or less commonly black, colour, connoting increased content of ferromagnesian minerals. They fall into three closely related, but increasingly basic, sub-groups:—(i) quartz-hornblende-diorite porphyrites, (ii) quartz-hornblende-augite-diorite porphyrites, and (iii) labradorite-porphyrites. Sub-groups (i) and (ii) can only be distinguished from one another under the microscope.

(i) *Quartz-hornblende-diorite porphyrites.*

These are greenish, medium to fine-grained, holocrystalline, equigranular rocks, consisting of brown hornblende and andesine felspar, with subordinate amounts of orthoclase, quartz, iron ores and apatite, and secondary minerals, notably sericite, chlorite, calcite, epidote, albite, and quartz.

The hornblende occurs as abundant idiomorphic prisms, showing strong pleochroism with X = Y = light yellow, Z = reddish-brown or brown, and an extinction angle of $Z \Lambda c = 22°$ (approx). Zoned crystals are common, and in these the extinction angle $Z \Lambda c$ for the cores is about 17°-18°, for the intermediate zones about 19°-20°, and for the outer zone 22°. This may indicate, according to Kennedy and Read (22, p. 127) a progressive enrichment of the hornblende in Mg and Fe during its crystallization, an early common hornblende [H_2 Na Ca_2 (Mg, Fe) $_4Al_3Si_6O_{24}$] giving place to a pargasite [H_2 Na Ca_2(Mg, Fe)$_5$Al Si_7O_{24}]. The hornblende is generally more or less altered to an apple-green chlorite which retains the outlines, and often the cleavages of the hornblende crystals.

A number of the hornblende crystals enclose a core of colourless augite with 2V about 50°, or are moulded upon such augites (calcic pigeonites ?). This feature has been described by Junner (21, p. 158) as charcteristic of the hornblende in the hornblende-diorite-porphyrites of the Wood's Point-Walhalla dyke swarm. There, however, two varieties of pyroxene are found enclosed by the hornblende crystals, (i) a colourless augite, and (ii) a titaniferous enstatite-augite, or pigeonite with a very low optic axial angle.

Andesine (Ab_{65}) is the dominant felspar of these porphyrites, and is generally of later crystallization than the hornblende. Together with subordinate orthoclase and quartz, it forms allotriomorphic, or sometimes tabular, crystals which enclose the hornblende. It is frequently much altered to sericite if the hornblende is replaced by chlorite.

The quartz frequently occurs as ovoids of allotriomorphic grains in intimate association with crystals of bright yellow epidote, and lesser amounts of calcite, chlorite, and occasionally (?) albite. Such quartz is of secondary origin, and from the general association of quartz throughout the rock with secondary minerals it is a question whether most of the quartz is not of secondary origin, derived from the alteration of the felspars and hornblende by invading mineralizers. Hornblende phenocrysts are found crowded about the edges of the ovoids, with their longer axes tangential to the edges, so that the growth of the quartz-epidote areas must have preceded complete consolidation of the rock, i.e., the alteration of the rocks must have been deuteric.

(ii) *Quartz-hornblende-augite-diorite Porphyrites.*

The rocks of this sub-group contain less hornblende than those of the former, but their chief distinction is that they possess a second generation of pyroxene, which has crystallized later than the hornblende, and belongs to the groundmass. It is colourless, relatively calcic (?) pigeonite, with 2V about 40° (compared against muscovite with 2V = 40°), and occurs either as idiomorphic or irregular crystals in the coarser-grained dykes, or in ophitic or intergranular intergrowth with plagioclase laths in the more doleritic types. Where ophitic it is often a pale violet, though not pleochroic; and the iron ores in the rock contain ilmenite, frequently altering to leucoxene. In some instances the pigeonite appears to have been entirely replaced by chlorite and epidote, since these minerals form pseudo-"ophitic" intergrowths with the andesine laths. Small, irregular, and intersertal areas of secondary quartz are associated with such intergrowths.

The earlier generation of pyroxene is also preserved in these rocks, as inclusions in the hornblende crystals, or within altered phenocrysts of plagioclase. Generally it is a colourless augite, but occasionally the included pyroxene is enstatite, showing a slight pleochroism from pale green to colourless.

In one section granophyric intergrowths of quartz and orthoclase may be observed in the groundmass, together with occasional myrmekite intergrowths. A similar feature was observed by Junner (21, p. 158) in some of the diorite-porphyrites of the Woods Point-Walhalla series.

An analysis (Table 1, No. 6) has been made by Mr. Field of a typical specimen of this group, from Harris Hill, Parish of Colac Colac. The hornblende is almost completely altered to chlorite, but, as may be seen by comparing the analysis with analysis No. 7 of the table, it is closely comparable with the propylitized diorite-porphyrites of the Woods Point-Walhalla swarm.

(iii) *Labradorite-porphyrites.*

These are dense black rocks, studded with glassy felspar phenocrysts, which may be 2 to 3 mm. long. They are easily recognized in the hand specimen, and are less numerous than the diorite-porphyrites. They compare most closely in appearance with the chilled border phases of the felspar-hornblende-porphyrite dykes of Warburton (11), but are more basic.

In thin section they are seen to consist of strongly zoned idiomorphic columnar crystals of labradorite (Ab_{45}) with a maximum extinction angle in the symmetrical zone of 30°, set in a pilotaxitic groundmass of stumpy andesine laths, chloritized brown hornblende prisms and fibres, and granular iron ore. The outermost zone of the phenocrysts is andesine (Ab_{60}), of composition similar to that of the groundmass felspars. In some specimens the felspar is quite fresh; in others it is strongly sericitized, and a little secondary quartz is developed. The chloritization of the hornblende and the sericitization of the felspar appear to be of comparable degree. No augite has been observed in this subgroup.

A chemical analysis was made of a typical specimen from Tintaldra (Table 1, No. 8). It is more basic than the quartz-hornblende-diorite dykes, but equally rich in alumina, and with abundant lime and magnesia. In many respects it resembles a basalt. The nearest approach to it among rocks of related suites is the meta-basalt of Marysville (17).

6. Red Granites of Pine Mountain and Mt. Mittamatite.

The granites of these two stocks are identical in appearance. They are fine-grained equigranular, pink to reddish, potash granites, distinctly poor in ferromagnesians by contrast with the grey Corryong granite.

In thin section they are seen to consist of quartz, vein-perthite, and orthoclase, subordinate oligoclase, a small amount of green biotite, chlorite, and epidote possibly pseudomorphous after hornblende, and a little iron ore. The pink colour of the rock is due to the presence of innumerable specks of (?) hematite in the orthoclase. The dust is absent from the perthite veins. The oligoclase is somewhat sericitized, and is often found as a "sieve structure," invaded by the orthoclase. In the final stages of disintegration these "sieves" give rise to numerous small, optically parallel, inclusions in the orthoclase. The oligoclase is mostly about Ab_{75} with cores of Ab_{70}.

The biotite of these granites is similar to that in the granitic dykes, and is distinct from the brown biotite of the Corryong granite. It is pleochroic from yellow to green, even when not obviously chloritized. It contains occasional vaguely outlined inclusions which are pleochroic from pale yellow to brown, and are suggestive of brown hornblende. Small areas of chlorite and epidote, similar to those observed replacing hornblende in the quartz-felspar-hornblende porphyrites, occur scattered through the rock, and some have shapes suggestive of hornblende.

Chemically the Pine Mountain and Mt. Mittamatite granites are almost identical, and fall within the group of granites proper referred to earlier (p. 81). Their analyses (Table 1, Nos. 9, 10) are also closely comparable with that of the Jemba rhyolite, and with the analyses of the quartz-porphyry and red-porphyry dykes.

7. The Red Quartz-porphyry Dykes.

These are porphyritic dyke rocks with phenocrysts of glassy quartz and red felspar in a dense reddish groundmass. The felspar consists of orthoclase and vein-perthite, which form clots of allotriomorphic crystals, and a minor amount of acid plagioclase. The orthoclase is very cloudy, being filled with minute specks of (?) hematite. Occasional microphenocrysts of green biotite, and colourless corroded garnet are present. The groundmass is coarsely micro-crystalline, and consists of quartz and felspar. The felspar is so strongly clouded with hematite dust as to be indeterminate, but is almost certainly orthoclase. Purple fluorite occurs in the groundmass, in association with chloritized biotite.

These dykes are somewhat coarser-grained than the earlier quartz-porphyry dykes, which they otherwise resemble. Like the two red granites a high proportion of their iron content is present as Fe_2O_3 (Table 1, No. 11) owing to the presence of so much hematite dust in the orthoclase, but otherwise the analysis is almost identical with that of the Jemba rhyolite, and quartz-porphyry.

Thickness of the Cover.

Minimum estimates can be made of the thickness of cover under which the Corryong granite batholith and the Red Granite stocks solidified. The shape of the Jemba rhyolite residual suggests that the rhyolite did not greatly overflow the Jemba basin. Since there is still over 2,000 feet thickness of rhyolite, the sediments enclosing the basin must have stood at least 2,000 feet above its floor, and were presumably higher, i.e., more than 4,000 feet above present sea-level. The general level of the top of the Corryong batholith in the northern part of the area is between 2,000 and 2,500 feet above sea-level. It must therefore have consolidated under a cover not less than 2,500 feet thick, and probably a good deal thicker.

The two Red Granite stocks rise through the Corryong granite to 3,340 feet and 3,310 feet above sea-level respectively. The level of their contacts with the Corryong batholith varies from 1,500 feet to 2,000 feet above sea-level, and rises to 2,500 feet on the N.E. side of Mt. Mittamatite. The Red Granites, therefore, penetrated between 800 feet and 1,350 feet into the Ordovician above the Corryong granite. If it is assumed that the Jemba rhyolite is contemporaneous with these later granites, then the Jemba basin had been formed by this time, so that the thickness of the original cover above the Corryong batholith was much reduced, although it must still have been more than 2,000 feet thick where the red granites were intruded. Since they rose about 1,000 feet into this cover, the minimum thickness of the cover indicated is about 1,500 feet.

The dyke swarms developed at considerably greater depths, since their outcrops are found mostly at 1,000 feet or more below the summits of the Red Granites. Their extension in depth cannot be gauged. Clearly, the differentiation of the Red Granite cupolas continued during a rise of several thousand feet subsequent to the intrusion of the dykes.

These minimum values, whilst more or less comparable with other estimates of the thickness of batholith roofs (Daly, 1, p. 126), indicate a relatively thin roof for the red granite stocks.

Age Relations of the Intrusions.

It can only be demonstrated that both series of igneous intrusion were later than the Devonian orogeny by which the Upper Ordovician rocks were folded. If this orogeny was delayed until the Middle Devonian period (18, p. 116), then the intrusion of the Corryong granite batholith (which includes the Koetong granite, and hence (27) the Tallangatta gneisses) can be tentatively placed as late Middle, or Upper Devonian.

The time interval between the intrusion of the Corryong granite, and the later Red Granite series, can be gauged only in terms of erosion. The exposure of the Corryong granite in the floor of the " fossil basin " or deep lead, preserved beneath the Jemba rhyolite, indicates that some thousands of feet of sediments had been removed in this area subsequent to the orogeny, and previous to the second period of intrusion. If the orogeny can be regarded as Lower Devonian in age, then the Corryong granite may be post-Lower Devonian, while the Red Granite series may coincide with a Middle or Upper Devonian minor orogeny. If the

Corryong granite, on the other hand is post-Middle Devonian, the Red Granite series cannot be older than Lower Carboniferous, and may be much younger.

This development of at least two periods of igneous intrusion within a single area is not unique to this part of Victoria. In the Wedderburn District (28) an earlier, coarse-grained granite with porphyritic orthoclase is intruded by a later finer-grained, pink granite which carries tourmaline; while, intrusive into both granites, are a series of quartz-porphyry dykes, with subordinate quartz-diorite porphyrite dykes.

The Red Granite Complex.

If it be assumed that the dyke swarm, the Jemba rhyolite, and the granites of Pine Mountain and Mt. Mittamatite, with their subsequent red porphyry dykes, were consanguineous, then a comprehensive picture of the second period of intrusion can be drawn.

The differentiated character of the dykes and the fact that the diorites do not grade into quartz-porphyry along their strike, but are distinctly later intrusions which have come up the same channels, makes it clear that the dykes as a whole are derived from different levels in a differentiated magma. The upper layers of granite were drawn off first, and solidified in the cooler parts of the crust. They were followed by quartz-porphyry dykes from rather lower and hotter levels; and subsequently, by diorite magma from still lower, hotter levels. In each instance, however, the previously intruded magma had chilled before the later magma approached its level, so that the later, hotter magma in each case cut through the previous injection. The series of intrusions may have been continuous at depth, or possibly pulsatory.

We may picture a series of cupolas of dioritic magma, differentiating to granite partially by crystallization differentiation and partly by assimilation (13), rising through the Corryong granite into the overlying sedimentary cover. In advance of some of the cupolas, but in continuity with them, a series of dykes extend into fissures, faults, or planes of weakness in the roof. In the Corryong granite these coincide mostly with the direction of the joint planes, while in the sediments, if sufficiently thick to overcome the influence of this underlying Corryong granite, they coincide with the strike of the beds. These dykes draw their supply of magma from the upper portions of the cupolas: and if they are sufficiently numerous, drain off all the upper differentiated layers, and then some of the diorite. The dykes congeal: and into them stopes the slowly rising magma, differentiating more and more to granite in its upper regions.

Two such cupolas (Pine Mountain and Mt. Mittamatite) rose right through the Corryong granite and 1,000 feet or more into the overlying sediments. Where channels were available, these two granites sent out red porphyry dykes before they consolidated.

Above some of the other (supposititious) cupolas, dykes did not form in great numbers, but plugs of magma were injected under pressure into the cool upper crust, where they contorted the sediments, and congealed as quartz-porphyry owing to their small bulk. Mt. Morgan and Mt. Unicorn are examples of such plugs; and there are others in Walwa.

In Jemba, however, where the several thousand feet of sediments elsewhere covering the Corryong granite had been removed, the magma burst through the surface when it still possessed sufficient energy to stope up for another 1,000 feet. The absence of dykes round the edge of the rhyolite mass may indicate that the magma here rose as a plug, as at Mt. Morgan and Mt. Unicorn: or that the first few dykes reaching to the surface served as the necessary channels, and tapped the upper layers of the cupola. The bulk and uniformity of the rhyolite, and the apparent absence of diorite, suggest that the first alternative is the more probable. Magma was extruded until a thickness of lava of sufficient strength and pressure to seal the cupola was attained.

Mechanics of Intrusion.

The mechanism by which such a cupola-dyke complex might form requires some consideration. The predominant factors in such an intrusion will be temperature and pressure.

The mode of operation of temperature in connexion with cupola intrusion has been adequately explained by Holmes (19, pp. 243-250), from the principles of convective circulation taken in conjunction with the large differences that exist between the thermal gradients maintained by convective currents and the much steeper gradients of the rise of fusion temperature with pressure (i.e. depth). As a result of this difference, the convection currents would maintain the magma at the top of the cupola well above its fusion point, and so long as the supply of heat from the main reservoir continued, this superheat would be available for fusing the material of the roof and sides nearby. The augmented magma and liberated crystals or blocks would be carried down by the return peripheral circulation, along or parallel to the enclosing walls. In this way the roof of the cupola would be gradually extended upwards so long as the supply of heat was maintained.

The pressures in such a system (ignoring the possibility of tectonic forces) will be due to three major factors: the weight of the overlying rocks, which will be proportional to their thickness; the pressure inherent in the magma from the presence in it of volatile substances above their critical temperatures; and the strength of the overlying (or containing) rocks.

The inherent pressure of the magma will act in the direction of expansion, while the strength of the rocks, which is limited, acts purely in a retaining fashion. The pressure of the overlying strata will tend to cancel out, since action and reaction are equal and opposite, so that only factors (2) and (3) are active.

When a cupola rises sufficiently close to the surface, the inherent "volatile" pressure of the magma, being in excess of the resistant strength of the invaded rocks, will tend to raise the roof of the cupola. Anderson (30, pp. 11, 12, Fig. 1) and Thomas (31, pp. 56, 57, Fig. 5) have shown that if the invaded rocks are homogeneous, a system of more or less concentric conical tensions will develop in them above the cupola: and if these are filled with magma, will give rise to cone sheets.

In the area under consideration, however, the invaded rocks are not homogeneous, but consist of folded sediments and granite, possessing well defined directions of weakness, namely the bedding planes of the sediments, and the joint planes of the granite. The effort of the cupola to lift its roof found relief therefore in the opening up of these pre-existing planes of weakness, rather than by the development of a system of conical tensions. As a result, instead of cone-sheets, a dyke swarm developed, concentrated above each cupola, and parallel in direction to either the strike of the sediments, or the joint planes of the granite, according as to which was locally predominant.

With the re-sealing of the openings by the dykes, the strength of the invaded rocks would be more or less restored, and at the same time the excess internal pressure due to the volatiles would be reduced or dissipated. The addition of further hot material from the depths to fill the part of the cupola drained off into the dykes would cause a repetition of this process, or would permit the process of rise by convection assimilation to continue, when the cupola would rise into and replace the dykes.

Corryong Batholith.

Inadequate exposures prohibit speculation as to the behaviour of the Corryong granite in depth, but it has the apparent form and characteristics of a batholith (1, p. 113 et seq.).

The batholith is rather more completely deroofed in the northern part of the area than in the south. Knowing the shape of the contact aureole, and assuming its absolute width as uniformly 500 feet, it is possible to indicate the contours of the still covered portions. In the north the original irregularities of the granite surface have been eroded away, and only disconnected remnants of the deeper re-entrants of sedimentary cover remain as roof pendants, with their major axes and their strike parallel to the average strike of the Ordovician strata around and above the batholith, as in the N.W. (Parishes of Burrowye and Koetong). Further south, however, the roof is diversified by two well defined salients and re-entrants, in the manner of Daly's diagram (p. 122, Fig. 42).

The outcrops of the granite salients are more or less linear and parallel to the strike of the invaded Ordovician. The discordant relation of the outcrops and the surface contours and the contours of the hidden granite surface indicate that these granitic ridges are steep sided. Their surfaces are diversified by minor peaks and saddles. Excellent examples on a large scale occur to the S.W. outside of the area, where the Tallangatta Creek has cut a course parallel to the Ordovician strike in an acutely-angled, downwardly-directed, wedge-shaped roof pendant of sediments. On either side of the stream are elongated ellipses of granite, bordered by uniform contact aureoles, the long axes of the ellipses also being parallel to the Ordovician strike.

Certain beds of sediment are probably much more prone to replacement than others, and since they will present themselves to the magma as lenticles elongated parallel to the strike, their direction will be impressed on the roof of the magma chamber, and so control the ultimate shape of the main body of magma. The strike of the invaded sediments presents, moreover, a direction of more easy access to the molten magma. In this way the surface of the magma chamber will always be diversified by a number of lenticular steep ridges, with intervening downwardly-directed wedges, all with their long axes parallel to the strike of the invaded sediments.

As the magma chamber increases and engulfs the intervening wedges of sediments, the strike direction of the sediments will be constantly impressed upon it.

In view of the apparent relation in origin of batholiths with orogenic movements, it is probable that the shape of the granite magma in its origin conforms more or less to the shape of the newly formed mountain region, or to the geosyncline from which the mountains sprang. The shape of the batholith at great depths, therefore, will be concentric with the shape of the mountains with which it originated, but in its upper regions it will conform with the strike of the sediments, quite apart from the relation of the strike to the shape of the original mountains, or of the still earlier geosyncline.

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